

**Deep Space One:
Preparing for space exploration in the 21st century**

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This October, NASA will take a revolutionary step with the launch of the New Millennium program's Deep Space One (DS1) mission. DS1 will fly by asteroid 1992KD in July of 1999 and will then be on a trajectory toward comet 19P/Borrelly (see Figure 1).

The target bodies, however, are not what makes DS1 revolutionary. NASA has flown missions past comets and asteroids before. The pioneering role of DS1 lies in the fact that it will pave the way for future, even more exciting, space achievements by validating a host of technologies that are mature but still lacking a deep space demonstration. The New Millennium Program's primary focus is to identify and flight validate new, advanced technologies that hold great promise for revolutionizing observations from earth orbit or in deep space. However, because these technologies have not been demonstrated in space they are perceived to present a fairly high risk to missions that use them for the first time.

To help reduce the costs and risks to future missions that use these technologies, the program will send a series of dedicated "technology demonstration" missions into deep space and around Earth to test these technologies and prove that they work in space.

The program's soliciting of advanced technologies for space flight demonstration and validation will also stimulate the development of technologies around the nation and will strengthen the nation's technological infrastructure, making it more competitive in

the global market. Finally, many of these technologies will have commercial spin-offs that will benefit the public in their daily life.

The technical innovations that will be demonstrated on DS1 will comprise many of the foundation technologies supporting the next generation of deep space missions. Foremost among these will be solar electric propulsion (SEP). In the next century SEP will enable a whole class of ambitious missions that are simply impractical or unaffordable with standard chemical propulsion systems. In addition to SEP, DS1 will validate eleven other technologies including a multispectral imager and an integrated space physics ensemble.

The principal of SEP design (Figure 2) is similar to that of a basic rocket motor where gasses are generated in a contained area and directed out one opening in the containment. This creates an uncompensated force on the opposite side of the combustion chamber which thrusts the motor forward. However the SEP design does not employ an oxidation-reduction chemical reaction between propellant and oxidizer to create the expanding hot gas. Instead a steady stream of the element Xenon is ionized in the rocket motor chamber. The ions are then accelerated by an electric field towards and through a grid maintained at 1280 volts. The accelerated ions pass through the grid and leave the rocket motor chamber. At a peak thruster operation power of 2300 watts, the thrust produced is about 90 millinewtons. At minimum thruster power of 500 watts, the thrust is 20 millinewtons (Cassani *et al.*, 1996; Raman and Lehman, 1997).

Although the thrust of SEP is small, a significant advantage is accrued because the 100000 Km/hour exhaust velocity of the ionized Xenon is many times greater than the exhaust velocity of a conventional chemical propulsion system. These high

exhaust velocities cause the specific impulse (a measure of efficiency - thrust divided by the mass ejected per unit time) of the DS1 ion propulsion system to be 3300 sec. This exceeds by an order of magnitude the specific impulse of a typical chemical propulsion rocket motor. The bottom line is that SEP requires far less propellant than a chemical rocket to deliver the same payload mass to a target.

The low thrust of SEP requires changes in evaluating mission design. Patience is required for the effect of the gentle thrust to accumulate so as to produce high spacecraft velocity. Therefore SEP is particularly appropriate for missions requiring high energy such as those intended to explore the inner solar system. For the same payload size, SEP can shorten interplanetary cruise times and permit utilization of fewer planetary swingby gravity assists than a chemical propulsion system.

Because of the ion propulsion system power requirements, DS1 requires a high-power solar array. This array, SCARLET II (Solar Concentrator Arrays with Refractive Linear Element Technology), is another one of the technologies to be validated on DS1. The pair of solar concentrator arrays with refractive linear element technology uses cylindrical Fresnel lenses to concentrate sunlight onto photovoltaic cells arranged in strips along the focus of the cylindrical lenses. A relatively small solar array area is actually covered by solar cells. The thicker glass cover provided by the lens system greatly reduces the susceptibility of the photovoltaic cells to radiation damage.

Each array is composed of four panels measuring approximately 160 cm. wide by 113 cm. long. Multijunction GaInP₂/GaAs/Ge photovoltaic cell modules are interconnected in series to produce 100 volts and about 2,300 watts at the beginning of

the mission (declining over the life of the mission as the arrays age and the spacecraft recedes from the Sun) (Murphy *et al.*, 1977)

The launch period for DS1 begins on October 15 of this year. The spacecraft will be launched from Cape Canaveral on the first Delta 7326 rocket, a low-cost member of the Delta II family. (DS1 is so small that even with this small launch vehicle, another spacecraft, SEDSAT-1, built by students at the University of Alabama in Huntsville, will be carried to Earth orbit.)

After DS1 has been completed initial checkout and certified by the mission operations team, the SEP system will begin thrusting. Instead of burning a strong short pulse of chemical propellant followed by a long interplanetary cruise, the ion drive will emit a very high velocity, tenuous stream of ionized xenon. This will create a very gentle but steady long period of thrust which will propel the spacecraft almost continuously during its interplanetary cruise (Rayman and Lehman, 1997).

Within about a month of launch, DS1 will have accomplished most of its major objectives of assessing the performance of its payload of advanced technologies. The diagnosed failure of a technology, even if it causes the loss of the mission, may still be a success, if it achieves the goal of reducing the risk for future science missions. It is in these future missions that the real science return of DS1 will be found. But this high risk project also will attempt to return science during its test flight.

Two scientific instruments, the Miniature Integrated Camera Spectrometer (MICAS) and the Plasma Experiment for Planetary Exploration (PEPE) will also be validated for the first time in space by DS1. The flight will also test an

onboard autonomous navigation system plus other autonomy technologies, and a variety of telecommunications and microelectronics devices.

The Miniature Integrated Camera Spectrometer (MICAS) encompasses a camera, an ultraviolet imaging spectrometer and an infrared imaging spectrometer, all within one 12-kilogram (26-pound) package. It is derived from designs for fast flybys of the outer planets (Beauchamp *et al.*, 1995).

MICAS includes two visible wavelength imaging channels, an ultraviolet (UV) imaging spectrometer, and an infrared (IR) imaging spectrometer, plus all the thermal and electronic control. All sensors share a single 10-cm diameter telescope. Two visible-range detectors, both operating between about 500 and 1000 nm are used: a charged coupled device with 13-microrad pixels and an 18-microrad-per-pixel, metal-on-silicon active pixel sensor, which includes the timing and control electronics on the chip with the detector. The two imaging spectrometers operate in push-broom mode. The UV spectrometer spans 80 to 185 nm with 0.64-nm spectral resolution and 316-microrad pixels. The IR spectrometer covers the range from 1200 to 2400 nm with 6.6-nm spectral resolution and 54-microrad pixels

MICAS serves three functions on DS1. First, tests of the instrument performance establish its applicability to future space science missions. Second, it collects valuable science data during the mission, particularly during the asteroid flyby. Although science is not the primary goal of DS1, returning science data is an important part of the overall demonstration that all technologies are consistent with a mission that conducts science. Finally, MICAS is used to gather images for the Autonomous Navigation subsystem, another technology to be validated on D1.

This autonomous optical navigation (AutoNav) subsystem is the spacecraft's primary navigation system. It uses data already resident on the spacecraft or data acquired and processed onboard. Each image includes an object known as a "beacon" (a selected asteroid certain to be visible from the spacecraft) and known background stars. Images of four to five beacons are planned to be taken roughly three times per week during the initial checkout mission phase and then, with the exception of the encounter periods, roughly 12 beacons are imaged once per week during most of the remainder of the mission. Onboard image processing techniques allow accurate determination of the apparent positions of the asteroids with respect to the background stars. Asteroid ephemerides and star catalogs are stored in the autonomous subsystem software, therefore the spacecraft three-dimensional position is estimated. The heliocentric orbit is computed with a sequence of these position determinations. The trajectory then is propagated to the next encounter target and course changes are generated by the maneuver design element (Reidel *et al.*, 1997).

PEPE combines multiple instruments into one compact 6-kilogram (13-pound) package designed to determine the three-dimensional distribution of plasma over its field of view. PEPE includes a very low-power, low-mass micro-calorimeter to help understand plasma-surface interactions and a plasma analyzer to identify the individual molecules and atoms in the immediate vicinity of the spacecraft that have been eroded off the surface of asteroid 1992 KD. (Bolton *et al.*, 1997) It is a response to desires from within the space physics community to use common apertures with separate electrostatic energy analyzers to conserve power and mass in an integrated instrument (Sablik, 1990).

Thus PEPE combines several plasma instruments into one package. It measures electron and ion energies spanning a range of 3 eV to 30 keV, with a resolution of five percent. It also measures ion mass from one to 135 atomic mass units with 5 percent resolution. Using no moving parts, it electrostatically sweeps its field of view both in elevation and azimuth.

PEPE serves three functions. First, it validates the design for a suite of space physics instruments in one package. Second, it assists in determining the effects of the ion propulsion system on spacecraft surfaces and instruments and on the space environment, including interactions with the solar wind. And finally it conducts scientifically interesting measurements during the cruise and the encounter with asteroid 1992 KD. Analysis of PEPE data also will assure future users that there are no incompatibilities with space physics measurements and a spacecraft operating with solar electric propulsion.

Both MICAS and PEPE represent a new direction for the evolution of science instruments for interplanetary spacecraft. These two instruments incorporate a large fraction of the capability of five instruments that had typically flown on NASA's deep space missions.

The other technologies to be validated by DS1 are all directed toward improving the engineering environment in deep space. All can be expected to reduce costs and increase frequency of space exploration missions. In summary they are:

- Small Deep-Space Transponder – One of two new technologies related to telecommunications, the small deep-space transponder, designed to facilitate

telemetry (communication back and forth between mission control and the spacecraft), combines the spacecraft's receiver, command detector, telemetry modulation, exciters, beacon tone generation and control functions into one small, three-kg. (6.6-lb.) package.

- **K_a-Band Solid State Power Amplifier** – The second of DS1's new telecommunications technologies to be validated is a K_a-band solid state power amplifier. This band has rarely been used for telemetry, but, it will be used much more in future missions because it allows a smaller antenna and less power to be used to transmit the same amount of data as is now possible.
- **Beacon Monitor Operations** – The small deep-space transponder generates four tones that could prove a big help in reducing the large demand on NASA's Deep Space Network. The spacecraft determines its own health and need for human assistance. It selects one of four tones indicating its diagnostic findings, transmitting it to Earth so that mission control can decide what, if any, further action is needed.
- **Lower Power Electronics** – One of three DS1 experiments involving the reduction of electronics mass, volume and power consumption, this experiment validates the performance of a variety of electrical devices (including a ring oscillator, multipliers and discrete transistors) with very low voltage and capacitance, thus requiring significantly less power than comparable devices using conventional technology.
- **Multifunctional Structure** – The second of these three related experiments, this new packaging technology combines load-bearing elements with electronic housings and

thermal control, greatly reducing the mass of spacecraft cabling and traditional chassis.

- Power Activation and Switching Module – The last of the three electronics experiments, this device contains two sets of four power switches that feature quadruple the packing density of current switches.

One of the criticisms that has been levied against NASA in past years has been that the agency is unwilling to take the prudent risks necessary to incorporate bold, innovative technologies into deep space missions. The NASA administrator, Dan Goldin, has encouraged his agency to entertain greater risk in developing new missions; however, many members of the NASA panels that approve mission proposals are fearful of being identified with selecting a mission that subsequently failed. NASA managers are rewarded for mission success not for taking risk. Thus, they are most comfortable with missions that use components with a long heritage and systems configured to ensure the greatest possible redundancy in order to maximize the possibility of a 'work around' should a component fail. This is sometimes called the 'both belt and suspenders' approach to project management.

In the absence of a system that rewards risk, NASA needed to establish a method to demonstrate previously unvalidated technologies in deep space, thus reducing the associated risk. This led Goldin's Associate Administrator for space science, Wes Huntress, to spearhead the development of the New Millennium program, managed for NASA at its Jet Propulsion Laboratory. New Millennium was to be the final step in validating selected technologies so that they could be proposed for future missions.

without the stigma of risk. The technologies for validation include those for earth orbit as well as for deep space.

The Deep Space 1 mission is managed by the Jet Propulsion Laboratory for NASA's Office of Space Science, Washington, D.C. At NASA Headquarters, Dr. Wesley Huntress is associate administrator for space science. Ken Ledbetter is director of the Mission and Payload Development Division. Dr. Tom Morgan is the NASA program scientist for DS1. At the Jet Propulsion Laboratory, Dr. Fuk Li is program manager and Dr. David Crisp is the program scientist for the New Millennium Program. For Deep Space 1, JPL's David Lehman is project manager, and Dr. Marc Rayman is chief mission engineer and deputy mission manager, and Dr. Philip Varghese is mission manager. Leslie Livesay is the spacecraft manager, Curtis Cleven is the deputy spacecraft manager, and Peter Klupar is the Spectrum Astro project manager. The author, Dr. Robert Nelson is the DS1 project scientist. He acknowledges the assistance of John Watson, David Young, Jack Stockey, Marc Rayman, and Amy Snyder Hale for assistance in preparing this article. This work performed at Jet Propulsion Laboratory which is administered by CIT under contract with NASA.

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Figures Captions

Figure 1. Artist's conception of the DS1 spacecraft

Figure 2. Conceptual drawing of the DS1 Ion propulsion system

Figure 3. A) Line Drawing of the Miniature Integrated Camera and Spectrometer
with associated measurement characteristics.

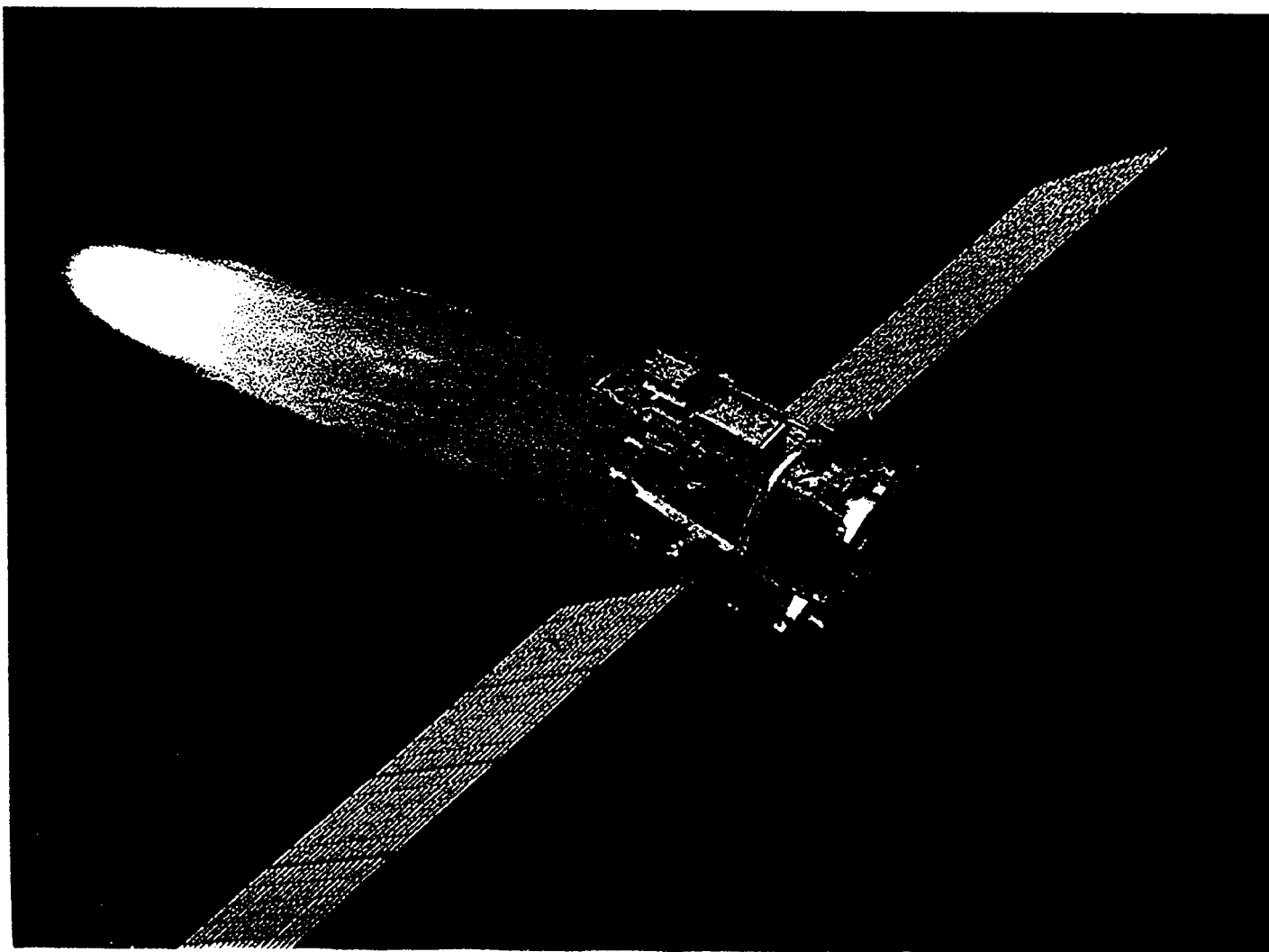
B) MICAS Optical design layout

Figure 4. Line drawing of the PEPE instrument.

Fig 1



Deep Space One



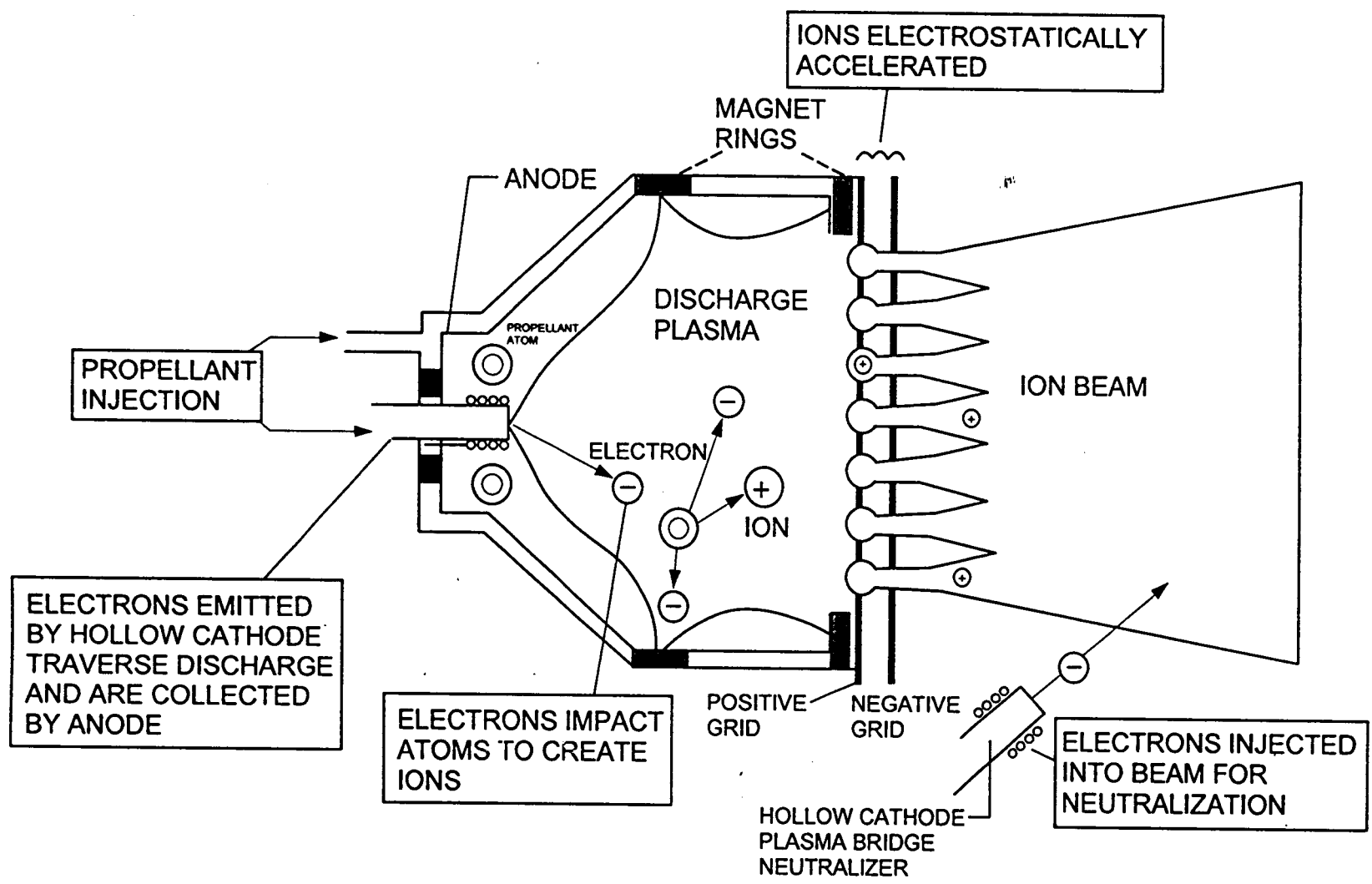
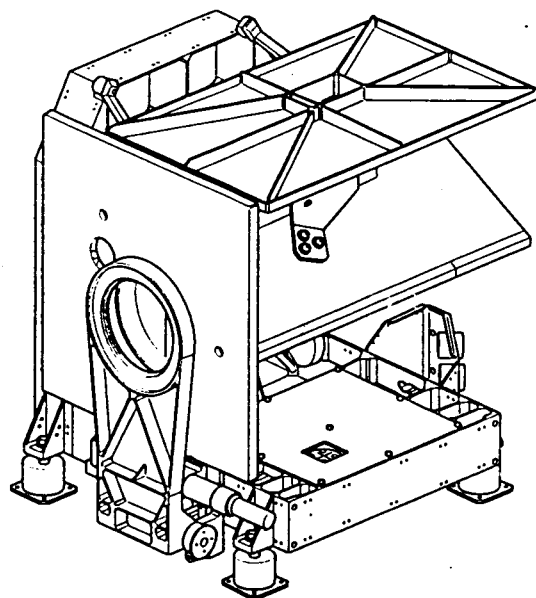
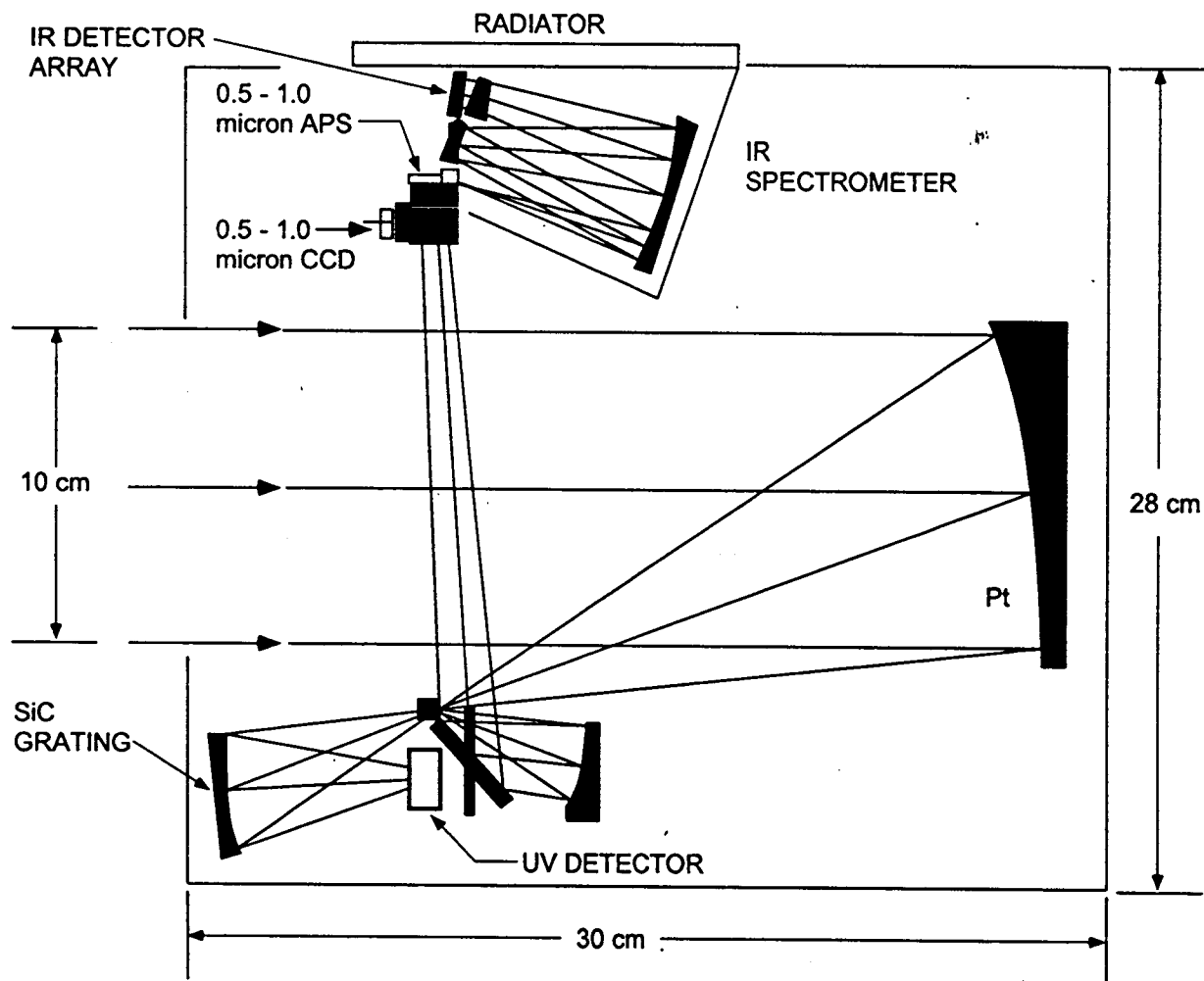


Fig 3a



MICAS Optics First Order Properties

	UV	Vis(APS)	Vis(CCD)	IR
Wavelength Range	80-185 nm	500-1000 nm	500-1000 nm	1200-2400 nm
Aperture Diameter	10 cm	10 cm	10 cm	10 cm
Effective Focal Length	17.1 cm	67.7 cm	67.7 cm	75.2 cm
F/#	1.7	6.8	6.8	7.5
Detector Array Size	35 x 164	256 x 256	1024 x 1024	256 x 256
Pixel Size	54 μm	12.0 μm	9.0 μm	40 μm
FOV	0.63 x 0.03 deg	0.26 x 0.26 deg	0.69 x 0.78 deg	0.7 x 0.003 deg
IFOV	316 μrad	18 μrad	13 μrad	53 μrad
Spectral Sampling Interval	0.64 nm/pixel	n/a	n/a	6.6 nm/pixel
Average Spectral Resolution	2.1 nm	n/a	n/a	12 nm



COLLIMATOR

GROUNDING
GRID

DEFLECTION
ELECTRODES

CERAMIC

CONDUCTING
RINGS

- IONS
- ELECTRONS
- ▨ LOW VOLTAGE ELECTRONICS
- ▤ HIGH VOLTAGE (HV) AREA
- PC BOARD
- ▤ CERAMICS INSULATORS

6.0"
(15 cm)

